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Antimicrobial Characteristics of Metal Deposited ACF Filters

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Abstract. Copper (Cu) and silver (Ag) known as antimicrobial materials were deposited on activated carbon fibers (ACF) by an electroless plating method. The metal deposited ACF filters were characterized by using SEM, EDX and XRD analyses. To verify the effects of metal deposition on the adsorptive characteristics of ACF filters, the specific surface area and pore structure were determined by BET equation and BJH method, respectively. The antimicrobial activities of metal deposited ACF filters against *E. coli, P. fluorescens, B. subtilis* and *M. luteus* were characterized by modified Kirby-Bauer method. By SEM-EDX and XRD analyses, it was confirmed that the electroless plating method was adequate for deposition of Cu and Ag on the surface of ACF filters. BET and BJH analyses showed that the micropore volume of metal plated ACF filters decreased compared to the pristine ACF filter. The inhibition zones, which represent the antimicrobial effects, were formed around the Cu and Ag deposited ACF filters whereas not in the case of pristine ACF.

Introduction

Activated carbon fiber (ACF) filters are widely used in air cleaning to remove hazardous gaseous pollutants such as volatile organic compounds (VOCs) because of their extended surface area and high adsorption amount. However, bacteria preferably adhere to solid supports made of carbon materials, indicating that ACF filters have good biocompatibility. Bacteria may breed on the ACF filters, so that the contaminated filters themselves become a source of bioaerosols [1]. In suitable hosts, bioaerosols are capable of causing acute or chronic diseases that may be infectious, allergenic, or toxigenic [2]. Volatile organic compounds produced by microbial metabolism (MVOCs) can be emitted from the filters [3]. In order to avoid such problems, antimicrobial treatment is required on ACF filters. In this study, antimicrobial metals such as copper (Cu) and silver (Ag) [4] were deposited on the surface of ACF filters by an electroless plating method. Electroless plating refers to the deposition of metal on a substrate by oxidation-reduction reaction without external electric current [5]. This procedure can yield mechanically durable fine metal layers with high specific surface areas. Ag and Cu deposited ACF filters were characterized using FE-SEM (Field Emission Scanning Electron Microscope), EDX (Energy Dispersive X-ray), XRD (X-ray Diffraction), BET and BJH analyses. Their antimicrobial activity was characterized by modified Kirby-Bauer method.

Methods

Copper and silver were deposited on the ACF filters (KF-1500, Toyobo) for 20 minutes by an electroless plating method, after the ACF filters were sensitized by immersion in an aqueous solution containing palladium for 5 minutes at 25 ^{o}C in order to maximize the autocatalysis [6].

Metal deposited ACF filters were characterized using FE-SEM (JSM-6500F, JEOL), EDX (JED-2300, JEOL) and XRD (Model D/MAX-Rint 2000, Rigaku). The nitrogen adsorption isotherms of ACF filters were measured by a porosimeter (ASAP 2010, Micromeritics Ins. Corp.) for characterization of pore structures.

Antimicrobial tests of metal deposited ACF filters were performed by modified Kirby-Bauer method. The bacterial suspensions were prepared by culturing again 0.1 mL of overnight cultures inoculated in 15 mL of nutrient broth for 18 hours. Nutrient broth was made by dissolving 5 g of peptone and 3 g of meat extract in 1000 mL of deionized water and then by sterilization with an autoclave. The suspensions were diluted with deionized water to obtain a base suspension with optical density of 0.1 at wavelength of 600 nm. Nutrient agar plates made by dissolving 5 g of peptone, 3 g of meat extract and 15 g of bacto agar in 1000 mL of deionized water were used for colonization of bacteria after autoclave. 0.1 mL of the prepared bacterial suspensions were spread on the nutrient agar plates. The test filter media were placed on the lawn of bacteria and incubated overnight. The antimicrobial activity was observed by visual inspection of diameters of the inhibition zone around the filter media. Bacterial strains and their optimal incubation temperatures are shown by table 1.

Table 1 Test strains used in this study.

Test bacteria (Gram)	ATCC	Temperature (^oC)
E. coli (-)	11775	37
P. fluorescens (-)	13525	26
B. subtilis (+)	6633	30
M. luteus (+)	10240	26

Result and Discussion

Fig. 1 shows SEM-EDX analyses of pristine and metal deposited ACF filters. Pristine ACF filter had smooth surface whereas ACF/Cu and ACF/Ag had fine particles on their surfaces. The particles shown in SEM micrographs were copper and silver particles as examined by EDX analyses.

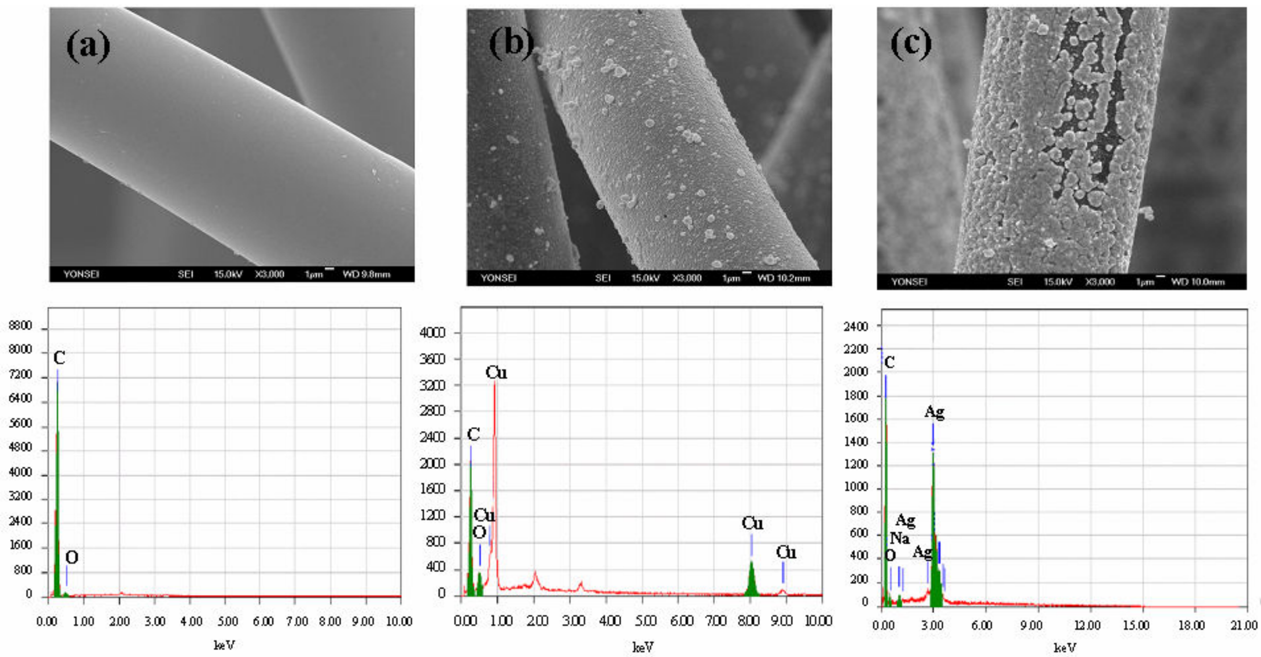

Fig. 1 SEM-EDX analyses of (a) pristine, (b) Cu deposited (ACF/Cu) and (c) Ag deposited (ACF/Ag) ACF filters.

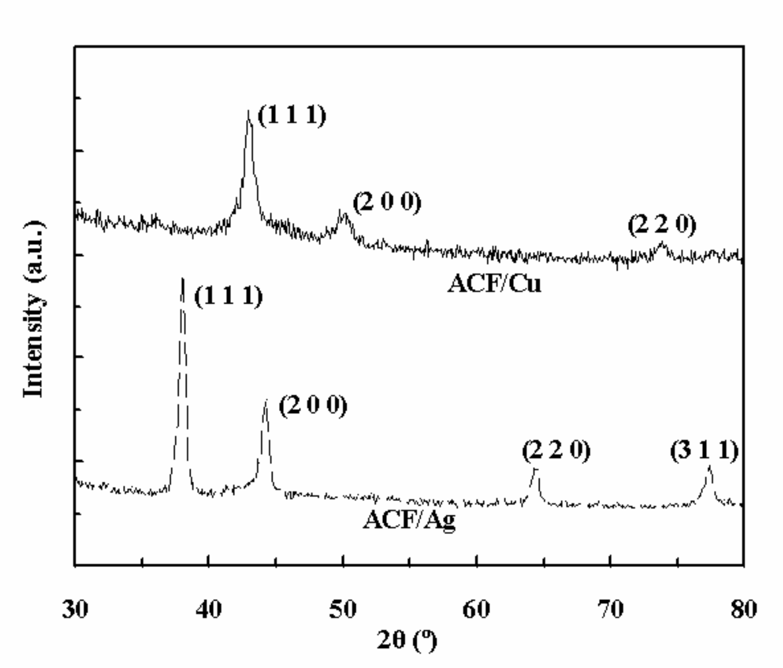

Fig. 2 XRD patterns of ACF/Cu and ACF/Ag.

Fig. 2 shows XRD patterns of ACF/Cu and ACF/Ag. In the case of ACF/Cu, peaks were found at around 2θ = 43 °, 50 ° and 74 ° corresponding to (111), (200) and (220) planes of the copper, respectively. The peaks of ACF/Ag were found at around 2θ = 38 °, 44 °, 65 ° and 78 ° and they were corresponded to (111), (200), (220) and (311) planes of the silver particles. Average crystallite sizes were estimated from the XRD line broadening of the (111) peak according to the Scherrer's equation (1).

$$d = \frac{0.9\lambda}{\beta \cos\theta}. \quad (1)$$

d is the average crystallite size, λ is the wavelength of X-ray used (CuKα=0.15418 nm) and β is the FWHM (Full-Width at Half Maximum). The averaged crystal sizes of copper and silver particles on the surfaces of ACF filters were 10.37 nm and 13.17 nm, respectively.

Table 2 shows the diameters of inhibition zones that represent the antimicrobial activities of pristine and metal deposited ACF filters. The inhibition zone was defined as the area that bacteria can not grow because of the antimicrobial activities of copper and silver particles on ACF filters. Pristine ACF filter did not form the inhibition zones whereas metal deposited ACF filters formed the inhibition zones of specific area. From these results, it was verified that metal deposition gave the antimicrobial characteristics to the ACF filter which does not have antimicrobial effect.

Table 2 Diameter of Inhibition zones of pristine and metal deposited ACF filters.

Materials	Diameter of inhibition zones (mm)			
	E. coli	*P. fluorescens*	*B. subtilis*	*M. luteus*
ACF	0	0	0	0
ACF/Cu	11.5	12.5	23.0	27.5
ACF/Ag	11.3	12.1	13.7	16.1

Table 3 Surface properties of pristine and metal deposited ACF.

Materials	TSSA (m^2/g)	MSSA (m^2/g)	TPV (cm^3/g)	MPV (cm^3/g)	APD (Å)
ACF	1,598	1583	0.91	0.86	17.7
ACF/Cu	865	860	0.59	0.55	16.6
ACF/Ag	1383	1347	0.58	0.55	17.0

*TSSA: Total specific surface area
*MSSA: Micropore specific surface area
*TPV: Total pore volume
*MPV: Micropore volume
*APD: Average pore diameter

Table 3 shows summarized properties related to the adsorptive characteristics of ACF filters determined from the raw data of nitrogen adsorption isotherms according to BET equation and BJH method. The total specific surface areas (TSSA), micropore specific surface areas (MSSA), total pore volumes (TPV), micropore volumes (MPV) and average pore diameters (APD) of the metal deposited ACF filters were decreased compared to pristine ACF filter. It is an important point that the adsorptive characteristics reduced due to the possible loss of the active sites for adsorption. Therefore, the controls of the metal amounts on ACF filters are needed for the determination of the optimized antimicrobial characteristics maintaining effective adsorptive amounts.

Summary

It was confirmed that the electroless metal plating method was adequate for the deposition of antimicrobial metals such as copper and silver on ACF filters. The metal deposited ACF filters showed antimicrobial activities due to copper and silver particles. Therefore, the metal deposited ACF filters can be used in air cleaning without offering the source of bioaerosols. Further study needs to be done on determining the optimized metal amounts on the surface of ACF filters for effective antimicrobial and adsorptive characteristics.

Acknowledgements

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